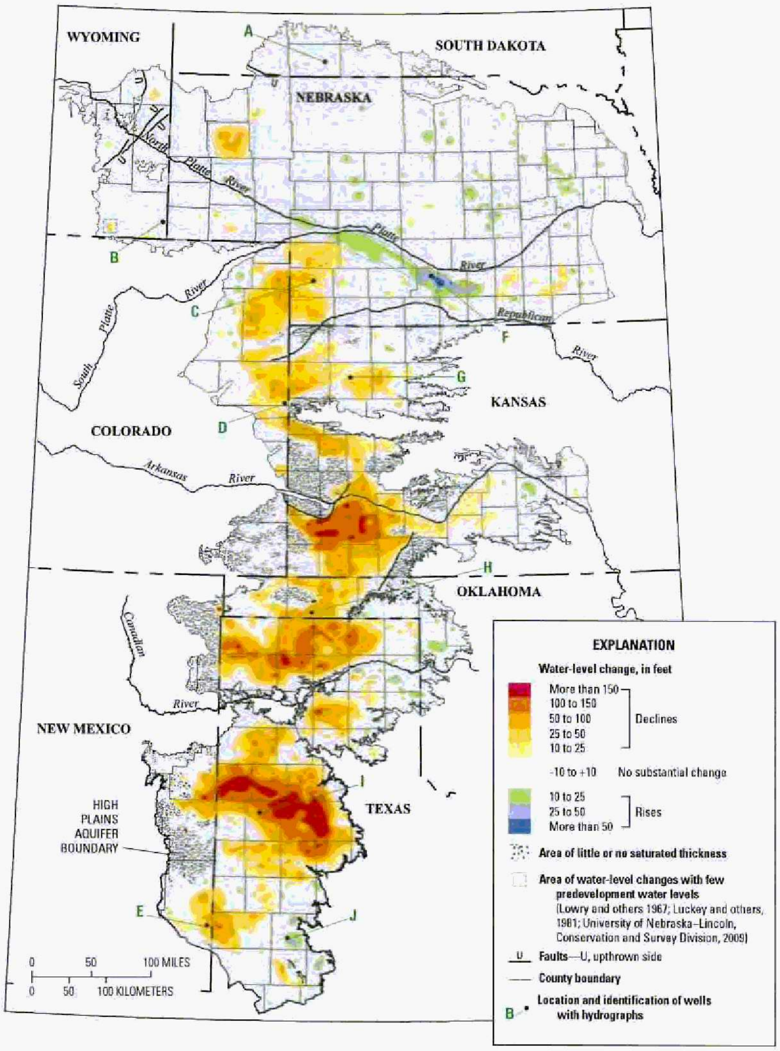
Exhibit 4

Groundwater Resources Program

Water-Level Changes in the High Plains Aquifer, Predevelopment to 2009, 2007–08, and 2008–09, and Change in Water in Storage, Predevelopment to 2009



Scientific Investigations Report 2011–5089

U.S. Department of the Interior
U.S. Geological Survey

Intensive Groundwater Use Control Areas (IGUCA)

- Water management tool that works in conjunction with the Kansas Water Appropriation Act
- Provides alternatives to strict administration of water rights by priority
- Allows for flexible solutions
- Chief engineer can amend an IGUCA in the public interest

KANSAS DEPARTMENT OF AGRICULTURE

Intensive Groundwater Use Control Areas (IGUCA)

- Eight IGUCA's are located in the state
- Formal public hearings are held
- KDA recently developed a regulation that provides for an independent hearing officer to decide initiation of an IGUCA
- If an IGUCA is designated, corrective control provisions are implemented through an order

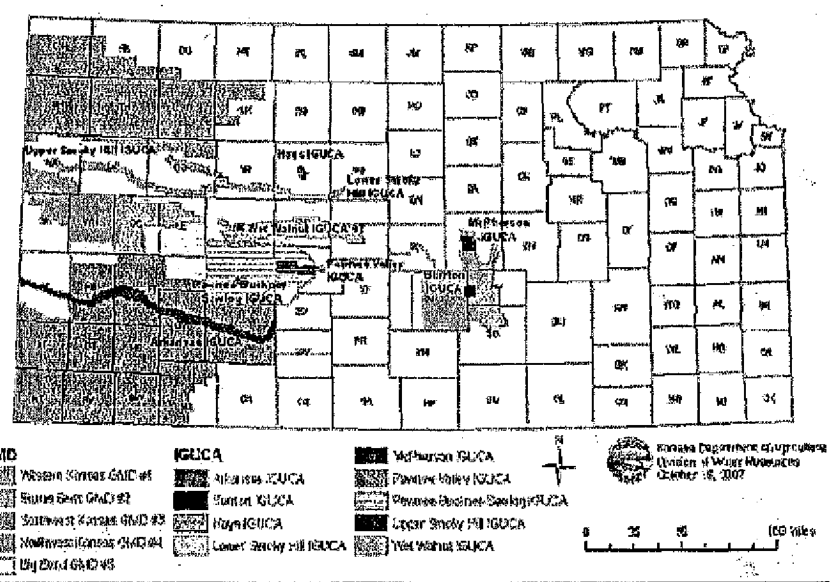
KANSAS DEPARTMENT OF AGRICULTURE

Intensive Groundwater Use Control Areas (IGUCA)

- Advisory committees/task forces have been established to make recommendations
- KDA also developed a new regulation to require formal reviews of IGUCAs to determine whether they should be continued

KANSAS DEPARTMENT OF AGRICULTURE

Intensive Groundwater Use Control Areas in Kansas



State Water Plan Storage Act

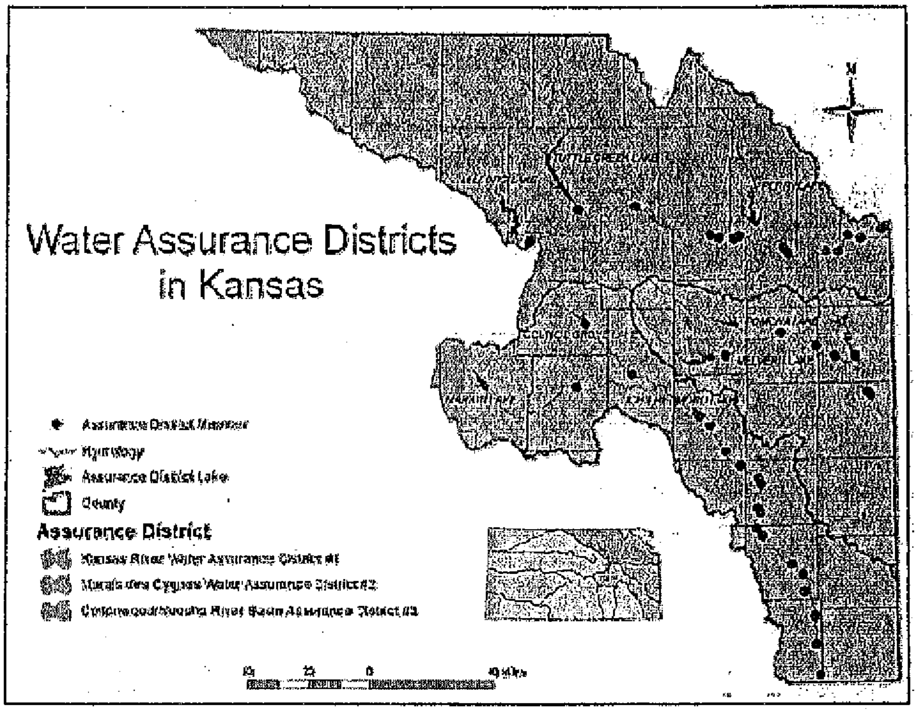
- Authorizes state-controlled storage in federal reservoirs
- Yield based on 2 percent chance of drought
- Considers existing and future needs of applicants
- Releases made pursuant to contracts
- Releases protected from use by other users

KANSAS DEPARTMENT OF AGRICULTURE

Water Assurance Program Act

- Based on 1985 agreement with the Corps of Engineers
  - Requires state to protect water quality releases
- Allowed state to acquire additional storage at original cost
- Operate reservoirs as a system to meet downstream needs
- Limited to municipal and industrial water rights

KANSAS DEPARTMENT OF AGRICULTURE



Water Transfer Act

- Requires a hearing for any proposal to divert and transport 2,000 acre-feet of water or more per year for beneficial use at a location greater than 35 miles from the source
- Does not include a release of water from a reservoir to the water's natural watercourse for use within the natural watercourse or watershed, made under the authority of the state water plan

KANSAS DEPARTMENT OF AGRICULTURE

Water Transfer Act

- Presiding officer conducts a hearing and renders an initial order approving or denying an application for water transfer
- The review of the hearing officer's order is made by a panel consisting of the Chief Engineer, the Director of the KWO and the Secretary of KDHE or Director of the Division of Environment, which shall constitute the final order

KANSAS DEPARTMENT OF AGRICULTURE

Current Management

- All areas now closed or subject to "safe yield", comparing the source of supply vs. existing water rights
- Changes to water rights cannot increase consumptive use or impair other water rights
- Improved compliance and enforcement, water use reporting

KANSAS DEPARTMENT OF AGRICULTURE

Looking to the Future

- The state has a good set of laws to regulate water development and use, but challenges remain
  - Non-sustainable development in western Kansas resulting in declining baseflow to streams, inflows to reservoirs; increased impairment complaints; uncertainty on future supplies
  - More firm supplies to meet future needs
  - Reservoir sediment reducing yields

KANSAS DEPARTMENT OF AGRICULTURE

Looking to the Future

- Kansas required to meet interstate compact commitments in addition to in-state needs
  - Using state-of-the-art computer modeling to evaluate supplies and management
  - Coordination and policy development through Kansas Water Authority and water plan processes, interaction with GMDs and other districts and stakeholders
  - Local input important, state control necessary

KANSAS DEPARTMENT OF AGRICULTURE

Looking to the Future

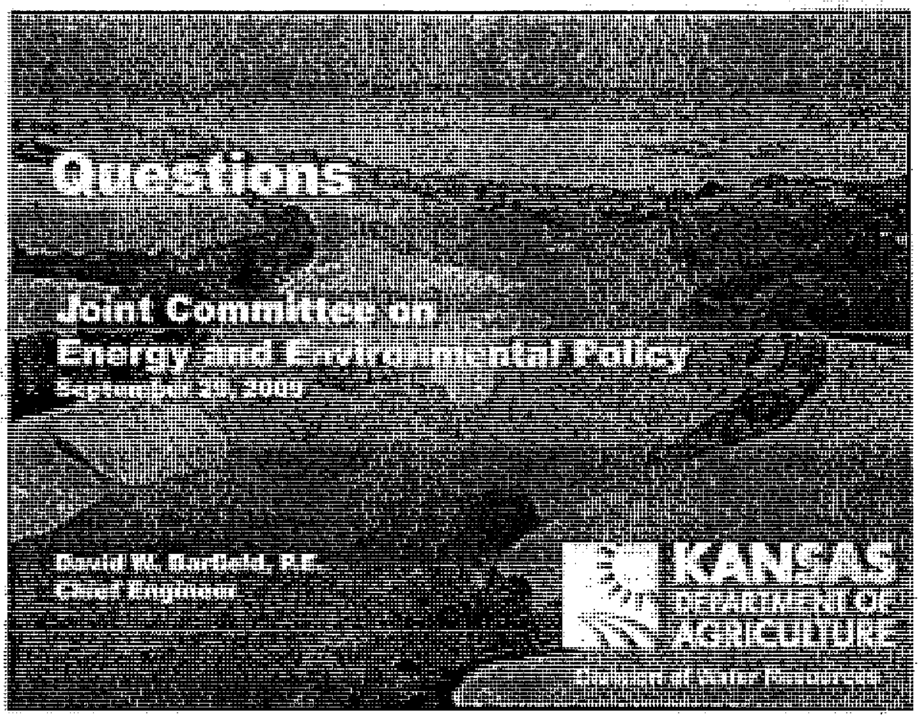
- Agencies charged to administer water laws need adequate resources and support
  - Division of Water Resources has experienced a 20 percent State General Fund budget reduction in fiscal years 2009 and 2010, which is resulting in a 20 percent staff reduction
  - Modest fee increases to sustain current services requested in 2009 were not passed

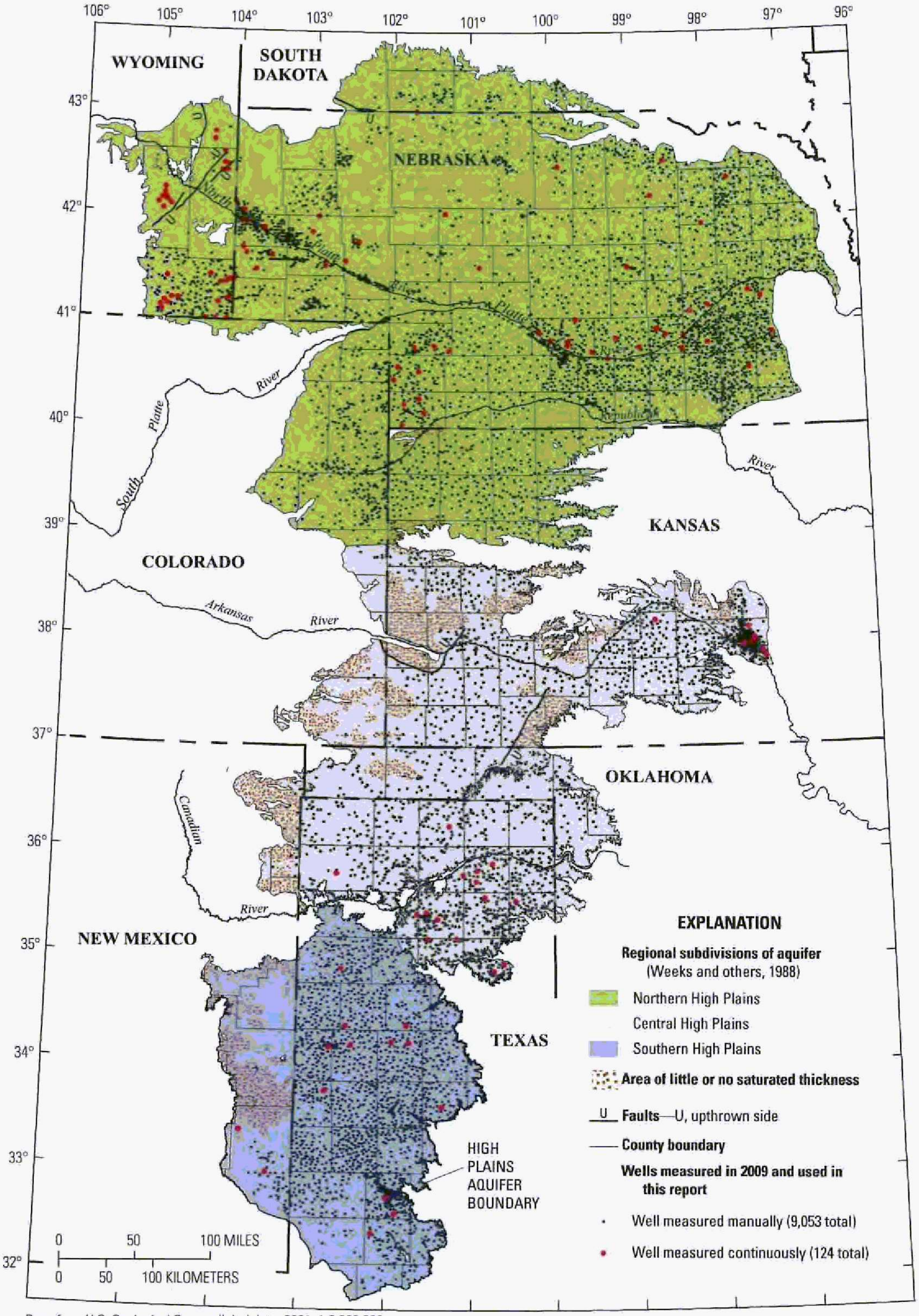
KANSAS DEPARTMENT OF AGRICULTURE

Topics for the Presentation in Afternoon

- Water use for energy production
- Water resources near Wolf Creek
- Wolf Creek water rights and assurance district contracts
- Options for securing additional water
- Kansas Water Office will discuss regional supplies

KANSAS DEPARTMENT OF AGRICULTURE


Questions
Joint Committee on
Energy and Environmental Policy
KANSAS
DEPARTMENT OF
AGRICULTURE



Base from U.S. Geological Survey digital data, 2001, 1:2,000,000
Albers Equal-Area projection
Standard parallels 29° 30' and 45° 30', central meridan -101°

Figure 1. Regional subdivisions of the High Plains aquifer and location of wells measured in 2009 and used in this report.

withdrawals for irrigation, but also includes groundwater withdrawals for public supply and other uses, evapotranspiration where the water table is near land surface, and seepage to streams, springs, and other surface-water bodies where the water table intersects the land surface (Maupin and Barber, 2005). Recharge to the aquifer primarily is from precipitation, but other sources of recharge include seepage from streams, canals, and reservoirs, and irrigation return flows (Luckey and Becker, 1999). Water-level declines may result in increased costs for groundwater withdrawals because of increased pumping lift and decreased well yields (Taylor and Alley, 2001). Water-level declines also can affect groundwater availability, surface-water flow, and near-stream (riparian) habitat areas (Alley and others, 1999).

In response to water-level declines, Congress directed the USGS to monitor water levels in the aquifer; in 1987, the USGS, in collaboration with numerous Federal, State, and local water-resources entities (see "Acknowledgments" section), began monitoring water levels in more than 7,000 wells. Water levels for 2007 were based on measurements from 9,297 wells, water levels for 2008 were based on measurements from 9,416 wells, and water levels for 2009 were based on measurements from 9,177 wells (table 1; fig. 1; Kansas Geological Survey, 2010; Texas Water Development Board, 2010; U.S. Geological Survey, 2011).

This report presents water-level changes in the High Plains aquifer from the time before substantial development of groundwater for irrigation to 2009, from 2007–08, and from 2008–09. The time before substantial development of groundwater for irrigation is termed "predevelopment" in this report; predevelopment generally is before about 1950, but, in some areas (for example in the north-central part of the Texas Panhandle), predevelopment is the late 1990s and in other areas (for example in north-central Nebraska), substantial development of groundwater for irrigation has not occurred to date (2011). Water levels used in this report generally were measured in winter or early spring, when irrigation wells typically were not pumping and water levels generally had recovered from pumping during the previous irrigation season. This report also describes the amount of drainable water in storage in the High Plains aquifer in 2009 and the change in the amount of drainable water in storage in the aquifer from predevelopment to 2009. Drainable water in storage is the fraction of water in the aquifer that will drain by gravity and can be withdrawn by wells. The remaining water in the aquifer is held to the aquifer material by capillary forces and generally cannot be withdrawn by wells. Drainable water in storage is termed "water in storage" in this report.

Table 1. Number of wells used in this report for 2007, 2008, and 2009 water levels, and for the water-level comparison periods—predevelopment to 2009, 2007–08, and 2008–09 by State, by regional subdivision of the High Plains aquifer, and in total.

	Number of wells measured			Number of wells used in water-level comparison for indicated period		
	2007	2008	2009	Predevelopment to 2009	2007–08	2008–09
State						
Colorado	496	502	357	263	456	343
Kansas	1,722	1,761	1,746	566	1,386	1,661
Nebraska	3,934	3,929	3,802	1,584	3,829	3,761
New Mexico	105	67	72	116*	37	38
Oklahoma	121	148	135	92	111	131
South Dakota	113	111	106	71	110	104
Texas	2,749	2,839	2,687	726	2,410	2,383
Wyoming	57	59	272	21	55	53
Regional subdivision of the High Plains aquifer (Weeks and others, 1988)						
Northern High Plains	4,933	4,914	4,873	2,096	4,711	4,569
Central High Plains	2,385	2,586	2,475	943	1,937	2,240
Southern High Plains	1,979	1,916	1,829	400	1,746	1,665
High Plains aquifer	9,297	9,416	9,177	3,439	8,394	8,474

*For 99 wells in the predevelopment-to-2009 water-level comparison period, 2005, 2006, 2007, or 2008 water levels were used instead of 2009 water levels because many wells in New Mexico are measured only once every 5 years or because the 2009 water level was not a static water level.

Data and Methods

Water-Level Data

The water level from the wells used in this report generally are measured with an electric or steel tape using methods similar to those described by Stallman (1971). Most of the wells are manually measured 1 to 2 times per year—generally in the winter or early spring and in late fall. Some wells are measured nearly continuously by using instrumentation (data recorders and sensors or floats) installed in the well that records the water level periodically (generally every 15 to 30 minutes) (Cunningham and Schalk, 2011). In 2009, 124 of the 9,177 wells measured and used in this report were measured continuously (fig. 1). The wells are measured by numerous Federal, State, and local water-resources agencies (see "Acknowledgments" section).

Characterizing Water-Level Changes, Predevelopment to 2009

The map of water-level changes from predevelopment to 2009 was developed by first using a geographic information system (GIS) (ESRI® Arc/Info™ version 9.3) to interpolate from point measurements to a grid of water-level changes (using the GIS function, TOPOGRID), and then modeling the TOPOGRID-output grid as a contoured surface using the "contour" GIS command (Environmental Systems Research Institute, 1992 and variously dated). The data inputs to the GIS TOPOGRID function were the water-level-change values from wells measured in both the predevelopment and 2009 periods and the contours of water-level changes, predevelopment to 2007 (McGuire, 2009). The initial water-level-change contours and supplemental water-level-change data from water-level measurement in other wells and from published maps were used to create the final water-level-change contours for the predevelopment to 2009 period. The supplemental water-level-change data were from:

1. Wells measured in the predevelopment period and in at least one of the 2005–08 periods, but not in the 2009 period;
2. Wells measured before June 15, 1978 (but not during or before the predevelopment period for the area), and in the 2009 period;
3. Wells measured in 1980 and 2009 and contours from published maps of water-level changes, predevelopment to 1980 (Luckey and others, 1981); and
4. For parts of the aquifer in Nebraska and Wyoming with few predevelopment water levels, contours from published maps of water-level changes since predevelopment (Lowry and others, 1967; Luckey and others, 1981; University of Nebraska–Lincoln, Conservation and Survey Division, 2009).

Characterizing Water-Level Changes, 2007–08 and 2008–09

Since 1988, annual area-weighted, average water-level changes had been calculated using Thiessen polygons (Thiessen, 1911) because a larger number of wells were available with water levels measured in both adjacent reporting years (1988–2009) and, therefore, the Thiessen polygon method produced a reasonable value for annual area-weighted, average water-level changes (Kastner and others, 1989; Dugan and others, 1990 and 1994; Dugan and Schild, 1992; McGrath and Dugan, 1993; Dugan and Cox, 1994; Dugan and Sharpe, 1996; McGuire and Sharpe, 1997; McGuire and Fischer, 1999; McGuire, 2001, 2003, 2004a, 2004b, 2007, and 2009). For this report, maps of generalized annual water-level changes, 2007–08 and 2008–09, were constructed using Thiessen polygons (ESRI® Arc/Info™ version 9.3) to maintain consistency with previous reports. Thiessen polygons apportion the water-level change in each well to an area around the well; the size and shape of each polygon depends on the well's proximity to neighboring wells. The area-weighted, average water-level change values for 2007–08 and 2008–09 were computed by summing the quantities equal to the area in acres of each Thiessen polygon multiplied by the actual water-level change value for each corresponding well, and then dividing the sum by the aquifer area, excluding areas with little or no saturated thickness. The maps of generalized annual water-level change for 2007–08 and 2008–09 are not included in this report because this report emphasizes long-term water-level changes; however, the associated area-weighted, average values of water-level change and change in water in storage are presented.

Calculation of Area-Weighted Average Water-Level Changes, Predevelopment to 2009

Starting in 2000, area-weighted, average water-level changes since predevelopment have been calculated using a gridded version of the map of water-level changes from predevelopment to the reporting year (2000, 2001, 2002, 2003, 2005, 2007, and 2009). The Thiessen polygon method was not used to calculate area-weighted, average water-level changes from predevelopment to the reporting year because there are a smaller number of wells available with water levels measured in both the predevelopment and the applicable report year periods, which could cause the Thiessen polygon-based method to produce unrealistic estimates in the areas where such wells were sparse (McGuire, 2001, 2003, 2004a, 2004b, 2007, and 2009; McGuire and others, 2003).

Using the grid-based method, area-weighted, average water-level changes from predevelopment to the reporting year was calculated by multiplying the cell area (61.8 acres) by the specified value for the associated polygon; summing the result; and then dividing the sum by the aquifer area, excluding the areas with little or no saturated thickness. Each polygon in the contour map of water-level changes represents a range in water-level changes, The specified value for the associated polygon typically was set to the mid-range value of the water-level-change range associated with the polygon. Alternatively, the specified value was set to 50 ft for areas of water-level rises greater than 50 ft, -150 ft for areas of water-level declines greater than 150 ft, and 0 ft for areas of little or no saturated thickness.

Calculation of Change in Water in Storage and Total Water in Storage

Change in drainable water in storage in the High Plains aquifer for each period was calculated using the area-weighted, average specific yield of 0.15 for the High Plains aquifer (Gutentag and others, 1984) and change in the saturated volume of the High Plains aquifer for the period from the corresponding water-level-change map. Specific yield of a rock or soil, with respect to water, is the ratio of (1) the volume of water, which the saturated rock or soil will yield by gravity, to (2) the rock or soil volume (Meinzer, 1923). The specific yield of the High Plains aquifer ranges from near 0 to 0.30 (Gutentag and others, 1984). In this report and to be consistent with previous reports (Kastner and others, 1989; McGuire, 2009), the change in saturated aquifer volume, predevelopment to 2009, was calculated as the sum of the changes in saturated volume for the predevelopment to 2000 period (McGuire and others, 2003), 2000 to 2007 period (McGuire, 2003, 2004a, 2004b, 2007, and 2009), 2007–08 period, and 2008–09 period.

Total water in storage in the High Plains aquifer in 2009 was calculated by summing the volume of water in storage in 2000 and the annual changes in water in storage, 2000 to 2009 (McGuire, 2003, 2004a, 2004b, 2007, and 2009). Water in storage in 2000 was derived by multiplying the saturated aquifer volume in 2000 by the area-weighted, average specific yield of the aquifer (0.15). The saturated aquifer volume in 2000 was calculated using a gridded version (61.8-acre cells) of the map of saturated thickness in 2000 (McGuire and others, 2003), multiplying the area of each cell times the midrange value of the associated saturated-thickness contour interval; and summing the results. Saturated thickness in 2000 was mapped as the difference between superimposed contours of the altitude of the water table in 2000 and contours of the altitude of the base of the aquifer (Weeks and Gutentag, 1981; Borman and Meredith, 1983; Borman and others, 1984; Hart and McAda, 1985; Juracek and Hansen, 1995; Luckey and Becker, 1999; Houston and others, 2003). Annual changes in water in storage for 2000–01, 2001–02, 2002–03, 2003–04, 2004–05, 2005–06, 2006–07, 2007–08, and 2008-09 were computed for each time period by multiplying the associated annual area-weighted, average water-level change by the aquifer area and the area-weighted, average specific yield of the aquifer (0.15).

Characterizing Change in Saturated Thickness, Predevelopment to 2009

Change in saturated thickness, predevelopment to 2009, was mapped by contouring the ratio of water-level change to predevelopment saturated thickness using predevelopment and 2009 water-level data and altitude data for the base of the aquifer. The contours were constructed initially by using TOPOGRID, a GIS function, and then modeling the output grid as a contoured surface using the "contour" GIS command (Environmental Systems Research Institute, 1992 and variously dated). The data inputs to TOPOGRID were the change in saturated thickness from wells measured in both predevelopment and 2009, as a percent. The initial changes in saturated-thickness contours were used with supplemental data to construct the final contours. The supplemental data were changes in saturated-thickness data, in percent, from:

1. Wells measured in the predevelopment period and in at least one of the 2005–08 periods, but not in the 2009 period;
2. Wells measured before June 15, 1978 (but not in or before the predevelopment period for the area), and in the 2009 period;
3. Wells measured in 1980 and 2009 and contours from published maps of water-level changes, predevelopment to 1980 (Luckey and others, 1981); and
4. For parts of the aquifer in Nebraska and Wyoming with few predevelopment water levels, contours from published maps of water-level changes since predevelopment (Lowry and others, 1967; Luckey and others, 1981; University of Nebraska–Lincoln, Conservation and Survey Division, 2009).

Water-Level Changes, Predevelopment to 2009

The map of water-level changes in the High Plains aquifer from predevelopment to 2009 (fig. 2) is based on water levels from 3,439 wells (table 1) and on other published data (Lowry and others, 1967; Luckey and others, 1981; University of Nebraska–Lincoln, Conservation and Survey Division, 2009). The other published data were used in areas in Nebraska and Wyoming with few predevelopment water levels (fig. 2). Water-level changes from predevelopment to 2009 ranged from a rise of 84 ft in Nebraska in the Northern High Plains subdivision to a decline of 234 ft in Texas in the Southern High Plains subdivision; 99 percent of the wells had water-level changes from predevelopment to 2009 that ranged from a rise of 41 ft to a decline of 178 ft. The area-weighted, average water-level change from predevelopment to 2009 was a decline of 14.0 ft; the area-weighted, average water-level change from predevelopment to 2009 by State ranged from a decline of 36.7 ft in Texas to no change in South Dakota. Area-weighted, average water-level change from predevelopment to 2009 by regional subdivision of the aquifer ranged from a decline of 34.3 ft in the Southern High Plains subdivision to a decline of 2.9 ft in the Northern High Plains subdivision (table 2). From predevelopment to 2009, water levels declined more than 10 ft in about 26 percent of the aquifer area, more than 25 ft in about 18 percent of the aquifer area, and more than 50 ft in about 11 percent of the aquifer area. In approximately 72 percent of the aquifer area, water-level changes ranged from a 10-ft decline to a 10-ft rise. In approximately 2 percent of the aquifer area, water levels rose more than 10 ft from predevelopment to 2009.

Hydrographs for 10 wells screened in the High Plains aquifer are presented (fig. 3) to illustrate changes in water levels at selected locations (fig. 2). The hydrographs show altitude of land surface, water levels, and the estimated base of the aquifer at each selected location. The hydrographs include water-level records for wells where water levels have declined (figs. 3*B*, 3*C*, 3*D*, 3*E*, 3*G*, 3*H*, and 3*I*), a well where water levels have risen (fig. 3*F*), a well where water levels have not changed substantially (fig. 3*A*), and a well where water levels have risen and declined (fig. 3*J*).

Water-Level Changes, 2007–08

Water levels were measured in 8,394 wells before the irrigation season in both 2007 and 2008 (table 1); the irrigation season generally begins in May, but the actual dates depend on location. Water-level changes in the measured wells ranged from about a 15-ft decline in Kansas in the Central High Plains subdivision to about an 11-ft rise in Texas in the Southern High Plains subdivision; 99 percent of the wells had water-level changes from 2007–08 that ranged from a decline of 8 ft to a rise of 7 ft. Water-level declines of 3 ft or greater occurred in 6 percent of the measured wells. The area-weighted, average water-level change in the High Plains aquifer from 2007–08 by State ranged from a 1.1-ft decline in Colorado to a 0.4-ft rise in Nebraska (table 2); area-weighted, average water-level change in the High Plains aquifer from 2007–08 by the aquifer's regional subdivisions ranged from a decline of 0.6 ft in the Central High Plains subdivision to a rise of 0.2 ft in the Southern High Plains subdivision. Overall, the area-weighted, average water-level change in the High Plains aquifer during 2007–08 was a 0.1-ft decline (table 2).

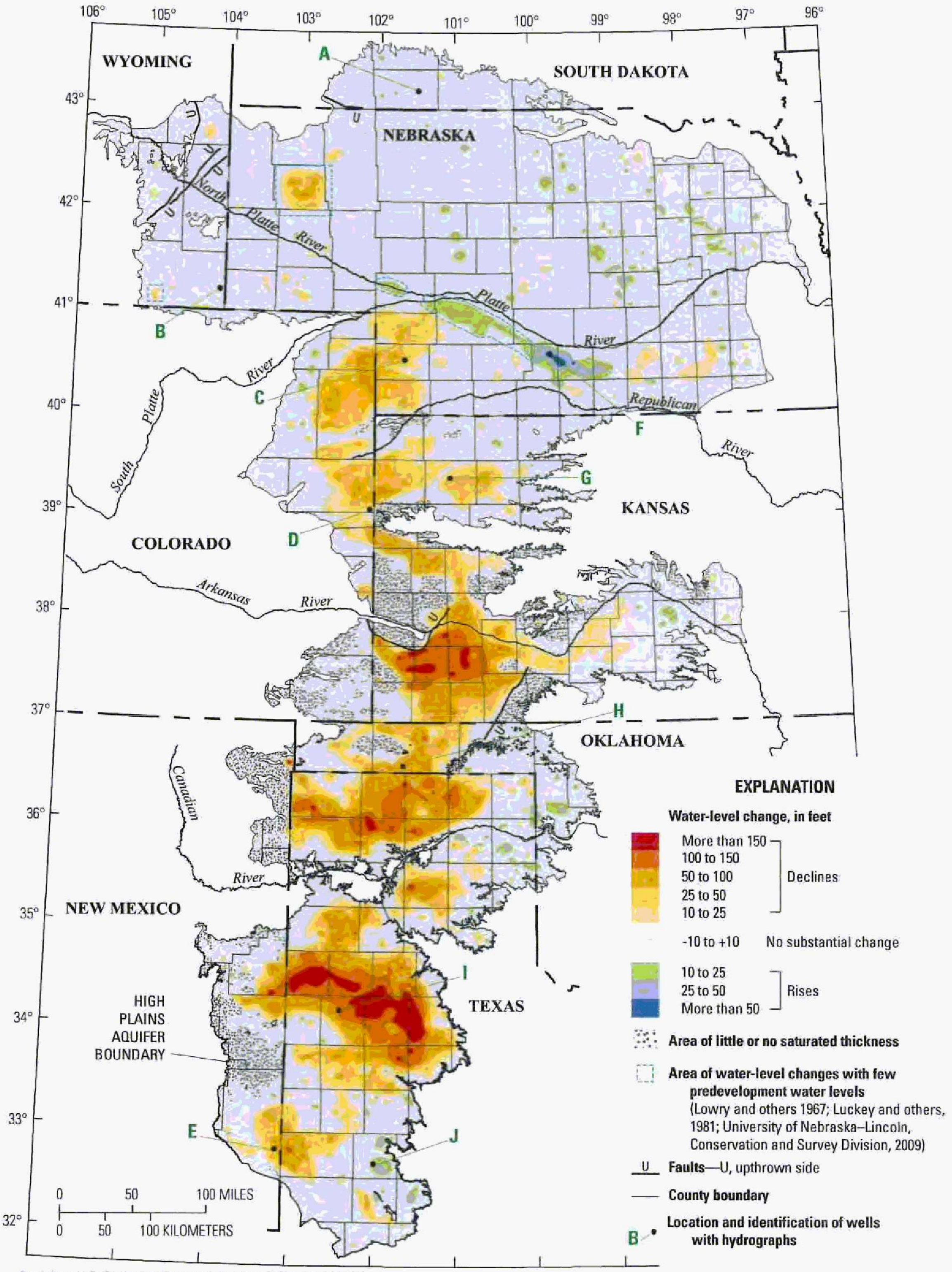
Water-Level Changes, 2008–09

Water levels were measured in 8,474 wells before the irrigation season in both 2008 and 2009 (table 1). Water-level changes in the measured wells ranged from about a 13-ft decline in Texas in the Southern High Plains subdivision to about an 11-ft rise in Nebraska in the Northern High Plains subdivision; 99 percent of the wells had water-level changes from 2008–09 that ranged from a decline of 9 ft to a rise of 7 ft. Water-level declines of 3 ft or greater occurred in 8 percent of the measured wells. The area-weighted, average water-level change from 2008–09 by State ranged from a 1.6-ft decline in New Mexico to a 0.4-ft rise in Nebraska (table 2); area-weighted, average water-level change from 2008–09 by the aquifer's regional subdivisions ranged from a decline of 1.1 ft in the Southern High Plains subdivision to a rise of 0.2 ft in the Northern High Plains subdivision. Overall, the area-weighted, average water-level change in the High Plains aquifer during 2008–09 was a 0.3-ft decline (table 2).

Table 2. Area-weighted, average water-level changes in the High Plains aquifer, not including the areas of little or no saturated thickness—predevelopment to 2009, 2007–08, and 2008–09 by State, by regional subdivision of the aquifer, and in total.

[Positive values for water-level rises; negative values for water-level declines.]

	Area-weighted, average water-level change		
	Predevelopment to 2009 (feet)	2007–08 (feet)	2008–09 (feet)
	State		
Colorado	-13.2	-1.1	-0.6
Kansas	-22.8	-.2	-.4
Nebraska	-.9	.4	.4
New Mexico	-15.1	-.4	-1.6
Oklahoma	-12.3	-.4	-.7
South Dakota	0	0	.1
Texas	-36.7	-.1	-1.1
Wyoming	-.4	-.5	.1
Regional subdivision of the High Plains aquifer (Weeks and other, 1988)			
Northern High Plains	-2.9	0.1	0.2
Central High Plains	-26.5	-.6	-.9
Southern High Plains	-34.3	.2	-1.1
High Plains aquifer	-14.0	-.1	-.3



Base from U.S. Geological Survey digital data, 2001, 1:2,000,000
Albers Equal-Area projection
Standard parallels 29° 30' and 45° 30', central meridan -101°

Figure 2. Water-level changes in the High Plains aquifer, predevelopment to 2009 (modified from Gutentag and others, 1984).

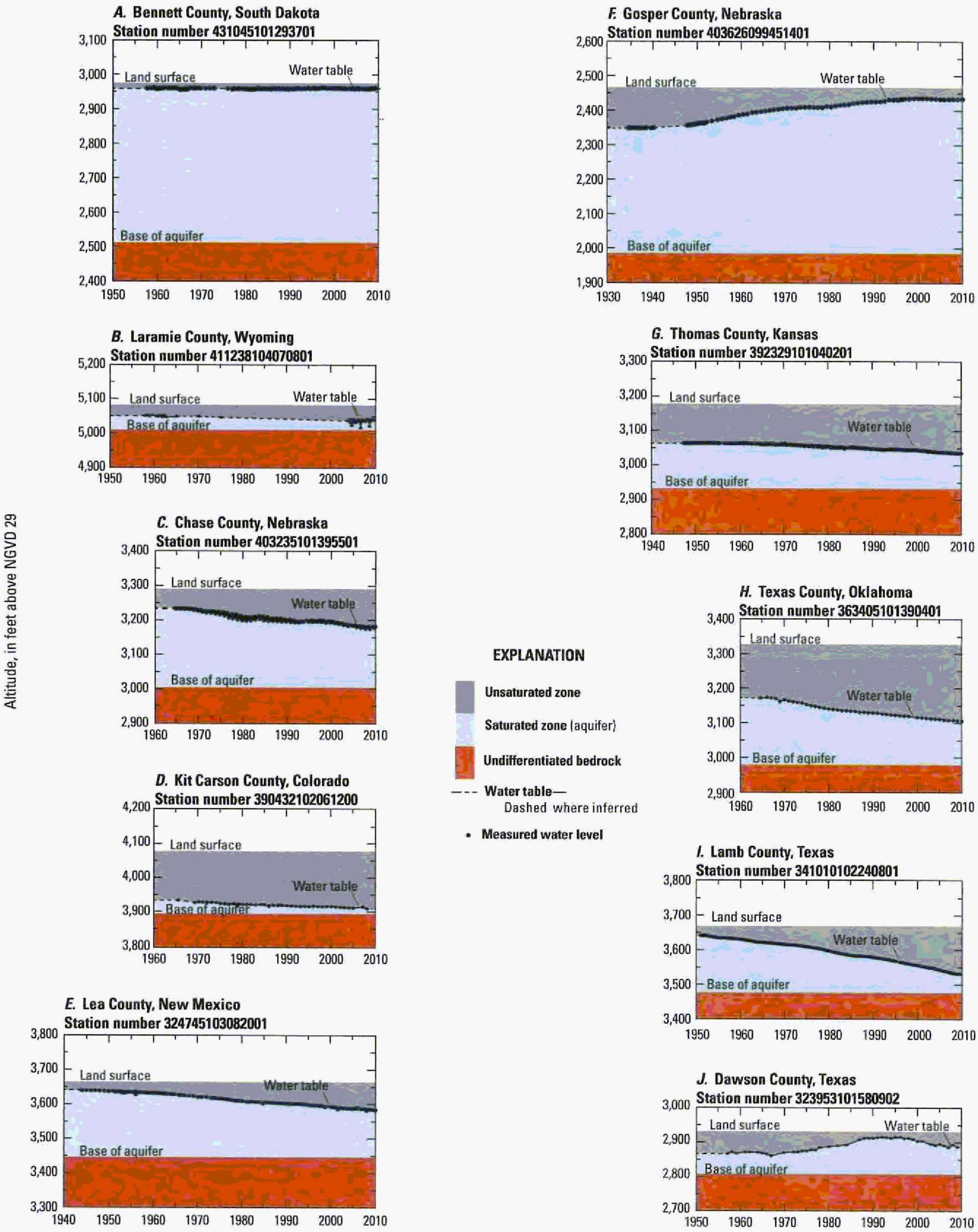


Figure 3. Hydrographs of water levels for selected wells. [See figure 2 for well locations; use station number to query water-level history in U.S. Geological Survey National Water Information System (U.S. Geological Survey, 2011)].

Change in Water in Storage, Predevelopment to 2009

Water in storage in the High Plains aquifer in 2009 was about 2.9 billion acre-ft (fig. 4), which was a decline of about 273 million acre-ft (or about 9 percent) since predevelopment storage (table 3). Changes in storage that may have occurred before the predevelopment period used for this report were not estimated.

The representation of a given change in the volume of water in storage in an area depends partly on the predevelopment saturated thickness of the aquifer. The map of percentage change in saturated thickness (fig. 5) presents predevelopment-to-2009 water-level changes as a percentage of predevelopment saturated thickness. This map (fig. 5) is similar in some areas to the water-level-change map (fig. 2); however, an area of large water-level change would not result in a substantial percentage change if predevelopment saturated thickness was large relative to the water-level change. Conversely, an area with small water-level change may result in a large percentage change in saturated thickness because of small predevelopment saturated thickness. By 2009, 13 percent of the aquifer area had more than a 25-percent decrease in saturated thickness since predevelopment, 5 percent of the aquifer area had more than a 50-percent decrease in saturated thickness, and less than 1 percent of the aquifer area had more than a 10-percent increase in saturated thickness.

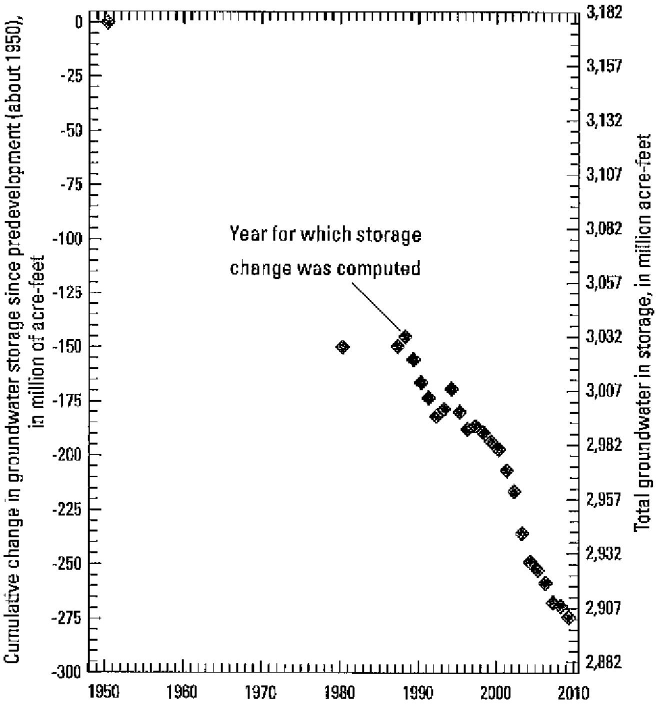


Figure 4. Cumulative change and total water in storage in the High Plains aquifer, predevelopment to 2009 (modified from McGuire, 2009).

Table 3. Change in water in storage in the High Plains aquifer, predevelopment to 2009, 2007–08, and 2008–09 by State, by regional subdivision of the aquifer, and in total.

[Positive values for increases in water in storage; negative values for decreases in water in storage]

	Change in water in storage		
	Predevelopment to 2009 (million acre-feet)	2007–08 (million acre-feet)	2008–09 (million acre-feet)
	State		
Colorado	-19.4	-1.3	-0.7
Kansas	-64.7	-.6	-1.1
Nebraska	-16.6	2.5	2.3
New Mexico	-11.4	-.2	-.9
Oklahoma	-13.0	-.3	-.5
South Dakota	-.5	0	.1
Texas	-144.5	-.5	-3.9
Wyoming	-2.6	-.4	.1
Regional subdivision of the High Plains aquifer (Weeks and other, 1988)			
Northern High Plains	-47.1	1.1	2.0
Central High Plains	-123.7	-2.5	-3.8
Southern High Plains	-102.3	.6	-2.9
High Plains aquifer	-273.0	-0.8	-4.7

Summary

The High Plains aquifer underlies 111.8 million acres (175,000 square miles) in parts of eight States—Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. Water-level declines occurred in parts of the High Plains aquifer soon after the onset of substantial irrigation with groundwater (about 1950). In response to water-level declines, Congress directed the U.S. Geological Survey to monitor water levels in the aquifer; in 1987, the U.S. Geological Survey, in collaboration with numerous Federal, State, and local water-resources entities, began monitoring water levels in more than 7,000 wells. Water levels were measured in 9,297 wells in 2007; 9,416 wells in 2008; and 9,177 wells in 2009. This report presents water-level changes in the High Plains aquifer from predevelopment (about 1950) to 2009, from 2007 to 2008, and from 2008 to 2009. The water levels used in this report generally were measured in winter or early spring, when irrigation wells typically were not pumping, and after water levels generally had recovered from pumping during the previous irrigation season. The report also presents changes in water in storage and saturated thickness from predevelopment to 2009.

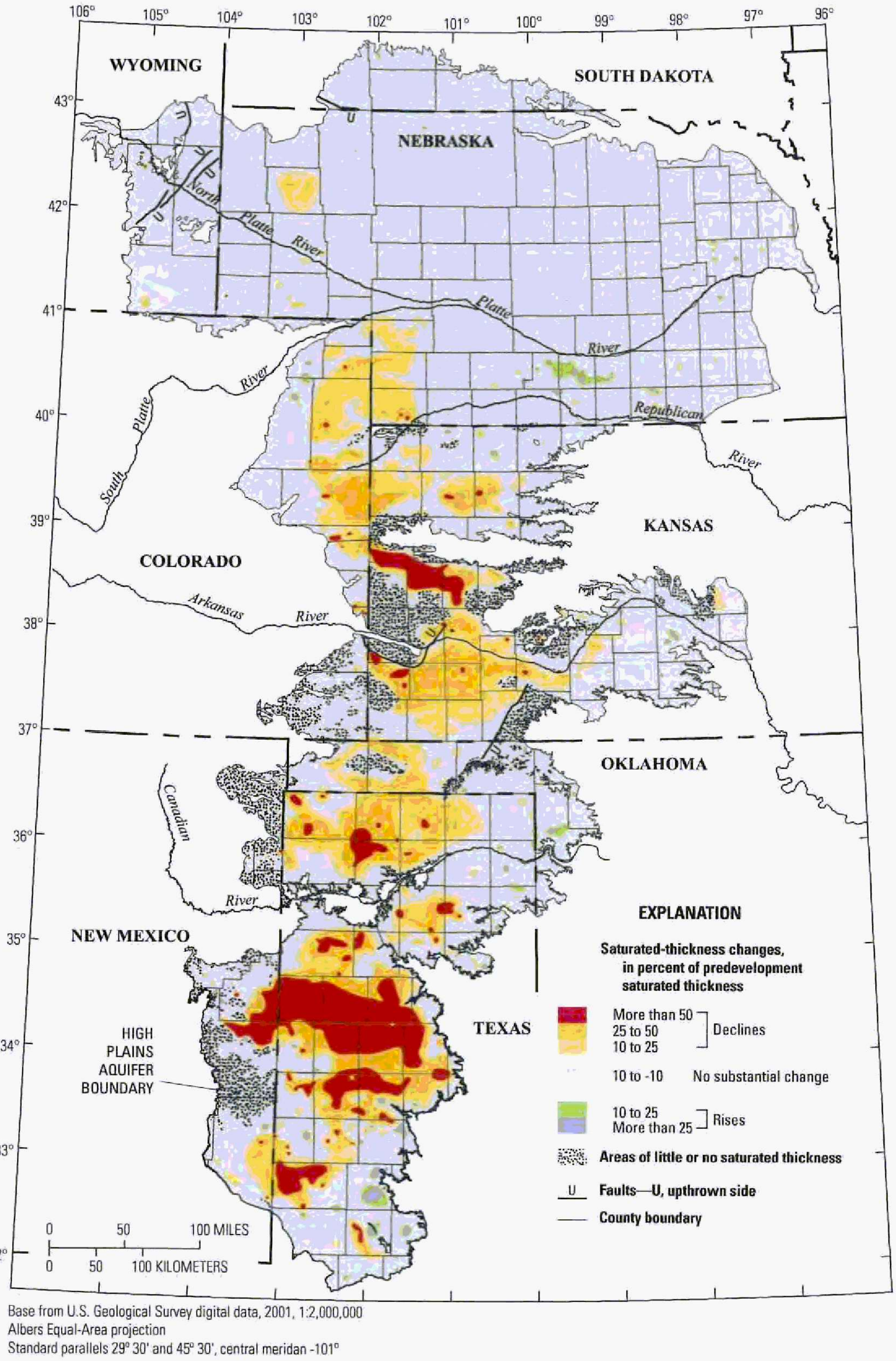


Figure 5. Change in saturated thickness of the High Plains aquifer, predevelopment to 2009 (modified from Luckey and others, 1981; Gutentag and others, 1984).

The map of water-level changes in the High Plains aquifer from predevelopment to 2009 is based on water levels from 3,439 wells and other published data. Ninety-nine percent of the wells had water-level changes from predevelopment to 2009 that ranged from a rise of 41 ft to a decline of 178 ft. The area-weighted, average water-level change from predevelopment to 2009 was a decline of 14.0 ft.

Water levels were measured in 8,394 wells before the irrigation season in both 2007 and 2008; 99 percent of the wells had water-level changes from 2007–08 that ranged from a decline of 8 ft to a rise of 7 ft. The area-weighted, average water-level change in the High Plains aquifer during 2007–08 was a decline of 0.1 ft.

Water levels were measured in 8,474 wells before the irrigation seasons in both 2008 and 2009; 99 percent of the wells had water-level changes from 2008–09 that ranged from a decline of 9 ft to a rise of 7 ft. The area-weighted, average water-level change in the High Plains aquifer during 2008–09 was a decline of 0.3 ft.

Total water in storage in 2009 was about 2.9 billion acre-ft, which was a decline of about 273 million acre-ft (or about 9 percent) since predevelopment. By 2009, 13 percent of the aquifer area had sustained more than a 25-percent decrease from its predevelopment saturated thickness, 5 percent of the aquifer area had more than a 50-percent decrease, and less than 1 percent of the aquifer area had more than a 10-percent increase.

References Cited

Alley, W.M., Reilly, T.E., and Franke, O.L., 1999, Sustainability of ground-water resources: U.S. Geological Survey Circular 1186, 79 p. (Also available at *http://pubs.usgs.gov/circ/circ1186/*.)

Borman, R.G., and Meredith, T.S., 1983, Geology, altitude, and depth of the bedrock surface beneath the Ogallala Formation in the northern High Plains of Colorado: U.S. Geological Survey Hydrologic Atlas 669, 1 sheet, scale 1:500,000. (Also available at *http://pubs.er.usgs.gov/djvu/HA/ha_669_plt.djvu*.)

Borman, R.G., Meredith, T.S., and Bryn, S.M., 1984, Geology, altitude, and depth of the bedrock surface; altitude of the water table in 1980; and saturated thickness of the Ogallala aquifer in 1980 in the southern High Plains of Colorado: U.S. Geological Survey Hydrologic Atlas 673, 1 sheet., scale 1:500,000.

Cunningham, W.L., and Schalk, C.W., compilers., 2011, Groundwater technical procedures of the U.S. Geological Survey: U.S. Geological Survey Techniques and Methods 1–A1, 151 p.

Dugan, J.T., and Cox, D.A., 1994, Water-level changes in the High Plains aquifer—Predevelopment to 1993: U.S. Geological Survey Water-Resources Investigations Report 94–4157, 60 p. (Also available at *http://pubs.er.usgs.gov/publication/wri944157*.)

Dugan, J.T., McGrath, T.J., and Zelt, R.B., 1994, Water-level changes in the High Plains aquifer—Predevelopment to 1992: U.S. Geological Survey Water-Resources Investigations Report 94–4027, 56 p. (Also available at *http://pubs.er.usgs.gov/publication/wri944027*.)

Dugan, J.T., and Schild, D.E., 1992, Water-level changes in the High Plains aquifer—Predevelopment to 1990: U.S. Geological Survey Water-Resources Investigations Report 91–4165, 55 p. (Also available at *http://pubs.er.usgs.gov/publication/wri914165*.)

Dugan, J.T., Schild, D.E., and Kastner, W.M., 1990, Water-level changes in the High Plains aquifer underlying parts of South Dakota, Wyoming, Nebraska, Colorado, Kansas, New Mexico, Oklahoma, and Texas—Predevelopment through nonirrigation season 1988-89: U.S. Geological Survey Water-Resources Investigations Report 90–4153, 29 p. (Also available at *http://pubs.er.usgs.gov/publication/wri904153*.)

Dugan, J.T., and Sharpe, J.B., 1996, Water-level changes in the High Plains aquifer—Predevelopment to 1994: U.S. Geological Survey Water-Resources Investigations Report 95–4208, 1 sheet, scale 1:2,381,000.

Environmental Systems Research Institute, 1992, Understanding GIS—the Arc/Info method: Redlands, Calif., Environmental Systems Research Institute, 450 p.

Environmental Systems Research Institute, variously dated, ArcDoc version 9.3: Redland, Calif., Environmental Systems Research Institute instructions provided with software.

Gutentag, E.D., Heimes, F.J., Krothe, N.C., Luckey, R.R., and Weeks, J.B., 1984, Geohydrology of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400–B, 63 p. (Also available at *http://pubs.er.usgs.gov/publication/pp1400B*.)

Hart, D.L., and McAda, D.P., 1985, Geohydrology of the High Plains aquifer in southeastern New Mexico: U.S. Geological Survey Hydrologic Atlas 679, 1 sheet. (Also available at *http://pubs.er.usgs.gov/djvu/HA/ha_679_plt.djvu*.)

Heimes, F.J., and Luckey, R.R., 1982, Method for estimating irrigation requirements from ground water in the High Plains in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Water-Resources Investigations Report 82–40, 64 p.

Houston, N.A., Garcia, C.A., and Strom, E.W., 2003, Selected hydrogeologic datasets for the Ogallala Aquifer, Texas: U.S. Geological Survey Open-File Report 2003–296, 1 CD-ROM.

Juracek, K.E., and Hansen, C.V., 1995, Digital maps of the extent, base, and 1991 potentiometric surface of the High Plains aquifer in Kansas: U.S. Geological Survey Open-File Report 95–758. (Also available at *http://www.kansasgis.org/catalog/index.cfm.*)

Kansas Geological Survey, 2010, Wizard water well levels database: Kansas Geological Survey data, accessed September 2010, at *http://www.kgs.ku.edu/Magellan/WaterLevels/index.html.*

Kastner, W.M., Schild, D.E., and Spahr, D.S., 1989, Water-level changes in the High Plains aquifer underlying parts of South Dakota, Wyoming, Nebraska, Colorado, Kansas, New Mexico, Oklahoma, and Texas—Predevelopment through nonirrigation season 1987–88: U.S. Geological Survey Water-Resources Investigations Report 89–4073, 61 p. (Also available at *http://pubs.er.usgs.gov/publication/wri894073.*)

Kenny, J.F., Barber, N.L., Hutson, S.S., Linsey, K.S., Lovelace, J.K., and Maupin, M.A., 2009, Estimated use of water in the United States in 2005: U.S. Geological Survey Circular 1344, 52 p. (Also available at *http://pubs.usgs.gov/circ/1344/.*)

Lowry, M.E., Crist, M.A., and Tilstra, J.R., 1967, Geology and ground-water resources of Laramie County, Wyoming, *with a section on* Chemical quality of ground water and of surface water by J.R. Tilstra: U.S. Geological Survey Water-Supply Paper 1834, 71 p. (Also available at *http://pubs.er.usgs.gov/publication/wsp1834.*)

Luckey, R.R., and Becker, M.F., 1999, Hydrogeology, water use, and simulation of flow in the High Plains aquifer in northwestern Oklahoma, southeastern Colorado, southwestern Kansas, northeastern New Mexico, and northwestern Texas: U.S. Geological Survey Water-Resources Investigations Report 99–4104, 68 p. (Also available at *http://pubs.usgs.gov/wri/wri994104/.*)

Luckey, R.R., Gutentag, E.D., and Weeks, J.B., 1981, Water-level and saturated-thickness changes, predevelopment to 1980, in the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA–652, 2 sheets, scale 1:2,500,000. (Also available at *http://pubs.er.usgs.gov/publication/ha652.*)

Maupin, M.A., and Barber, N.L., 2005, Estimated withdrawals from principal aquifers in the United States, 2000: U.S. Geological Survey Circular 1279, 46 p. (Also available at *http://pubs.usgs.gov/circ/2005/1279/.*)

McGrath, Timothy, and Dugan, J.T., 1993, Water-level changes in the High Plains aquifer—Predevelopment to 1991: U.S. Geological Survey Water-Resources Investigations Report 93-4088, 53 p. (Also available at *http://pubs.er.usgs.gov/publication/wri934088.*)

McGuire, V.L., 2001, Water-level changes in the High Plains aquifer, 1980 to 1999: U.S. Geological Survey Fact Sheet FS–029–01, 2 p. (Also available at *http://pubs.usgs.gov/fs/2001/fs-029-01/.*)

McGuire, V.L., 2003, Water-level changes in the High Plains aquifer, predevelopment to 2001, 1999 to 2000, and 2000 to 2001: U.S. Geological Survey Fact Sheet 078–03, 4 p. (Also available at *http://pubs.usgs.gov/fs/FS078-03/.*)

McGuire, V.L., 2004a, Water-level changes in the High Plains aquifer, predevelopment to 2002, 1980 to 2002, and 2001 to 2002: U.S. Geological Survey Fact Sheet 2004–3026, 6 p. (Also available at *http://pubs.usgs.gov/fs/2004/3026/.*)

McGuire, V.L., 2004b, Water-level changes in the High Plains aquifer, predevelopment to 2003 and 2002 to 2003: U.S. Geological Survey Fact Sheet 2004–3097, 6 p. (Also available at *http://pubs.usgs.gov/fs/2004/3097/.*)

McGuire, V.L., 2007, Water-level changes in the High Plains aquifer, predevelopment to 2005 and 2003 to 2005: U.S. Geological Survey Scientific Investigations Report 2006–5324, 7 p. (Also available at *http://pubs.usgs.gov/sir/2006/5324/.*)

McGuire, V.L., 2009, Water-level changes in the High Plains aquifer, predevelopment to 2007, 2005–06, and 2006–07: U.S. Geological Survey Scientific Investigations Report 2009–5019, 9 p. (Also available at *http://pubs.usgs.gov/sir/2009/5019/.*)

McGuire, V.L., and Fischer, B.C., 1999, Water-level changes, 1980 to 1997, and saturated thickness, 1996-97, in the High Plains aquifer: U.S. Geological Survey Fact Sheet 124–99, 4 p. (Also available at *http://ne.water.usgs.gov/ogw/hpwlms/graphics/97fs.pdf.*)

McGuire, V.L., Johnson, M.R., Schieffer, R.L., Stanton, J.S., Sebree, S.K., and Verstraeten, I.M., 2003, Water in storage and approaches to ground-water management, High Plains aquifer, 2000: U.S. Geological Survey Circular 1243, 51 p. (Also available at *http://pubs.usgs.gov/circ/2003/circ1243/.*)

McGuire, V.L., and Sharpe, J.B., 1997, Water-level changes in High Plains aquifer—Predevelopment to 1995: U.S. Geological Survey Water-Resources Investigations Report 97–4081, 2 sheets, scale 1:2,500,000. (Also available at *http://pubs.er.usgs.gov/djvu/WRI/wrir_97_4081_plt.djvu.*)

Meinzer, O.E., 1923, Outline of ground-water hydrology, with definitions: U.S. Geological Survey Water-Supply Paper 494, 71 p. (Also available at *http://pubs.er.usgs.gov/publication/wsp494.*)

Qi, Sharon L., 2010, Digital map of aquifer boundary for the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Data Series 543. (Also available at *http://pubs.usgs.gov/ds/543/.*)

Stallman, R.W., 1971, Aquifer-test design, observation, and data analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. B1, 26 p. (Also available at *http://pubs.er.usgs.gov/publication/twri03B1.*)

Taylor, C.J., and Alley, W.M., 2001, Ground-water-level monitoring and the importance of long-term water-level data: U.S. Geological Survey Circular 1217, 68 p. (Also available at *http://pubs.usgs.gov/circ/circ1217/.*)

Texas Water Development Board, 2010, Groundwater database: Texas Water Development Board data, accessed December 2010, at *http://www.twdb.state.tx.us/GwRD/waterwell/well_info.asp.*

Thelin, G.P., and Heimes, F.J., 1987, Mapping irrigated cropland from Landsat data for determination of water use from the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400–C, 38 p. (Also available at *http://pubs.er.usgs.gov/usgspubs/pp/pp1400C.*)

Thiessen, A.H., 1911, Precipitation averages for large areas: Monthly Weather Review, v. 39, p. 1,082–1,084.

University of Nebraska–Lincoln, Conservation and Survey Division, 2009, Groundwater-level changes in Nebraska from predevelopment to spring 2009: University of Nebraska–Lincoln, School of Natural Resources, Conservation and Survey Division, map graphic, accessed February 2011, at *http://snr.unl.edu/data/water/groundwatermaps.asp.*

U.S. Department of Agriculture, 1999, 1997 Census of agriculture, volume 1, geographic area series, part 51, United States: National Agricultural Statistics Service AC97–CD–VOL1–1B, CD–ROM.

U.S. Department of Agriculture, 2004, 2002 Census of agriculture, volume 1, chapter 2, County level data: National Agriculture Statistics Service data, accessed July 2006, at *http://www.agcensus.usda.gov/Publications/2002/index.asp.*

U.S. Geological Survey, 2008, Water use in the United States: U.S. Geological Survey groundwater-use data by county for 1985, 1990, 1995, 2000 and 2005, accessed December 2008, at *http://water.usgs.gov/watuse/.*

U.S. Geological Survey, 2011, National Water Information System: U.S. Geological Survey data. (Also available at *http://waterdata.usgs.gov/nwis/gw.*)

Weeks, J.B., and Gutentag, E.D., 1981, Bedrock geology, altitude of base, and 1980 saturated thickness of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA–648, 2 sheets, scale 1:2,500,000. (Also available at *http://pubs.er.usgs.gov/usgspubs/ha/ha648.*)

Weeks, J.B., Gutentag, E.D., Heimes, F.J., and Luckey, R.R., 1988, Summary of the High Plains regional aquifer-system analysis in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400–A, 30 p. (Also available at *http://pubs.er.usgs.gov/publication/pp1400A.)*

Publishing support provided by:
Rolla Publishing Service Center

For more information concerning this publication, contact:
Director, USGS Nebraska Water Science Center
5231 South 19 Street
Lincoln, Nebraska 68512
(402) 328–4100

Or visit the Nebraska Water Science Center Web site at:
http://ne.water.usgs.gov/

USGS

McGuire—**Water-Level Changes in the High Plains Aquifer, Predevelopment to 2009, 2007–08, and 2008–09**—Scientific Investigations Report 2011–5089